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Geomorphology and Holocene Growth History of the Cockatoo Island Fringing Reefs, Kimberley Bioregion, Northwest Australia

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Located in the Northwest region of Australia, Kimberley coral reefs have a unique environment with macrotidal conditions, hard substrate geology, and ongoing subsidence compared to a microtidal and no subsidence setting environment of the Great Barrier Reef (GBR) in the east coast of Australia. Despite the fact that the Kimberley coral reefs are living in inhospitable environments, the coral species are far richer than those of the inner GBR and a little richer than those of the Pilbara to the south. However, the other invertebrate fauna of the Kimberley are relatively impoverished (Wilson 2013).

Subsidence since the Last Interglacial has provided accommodation for growth of a Holocene reef upon older reef substrate, both exposed in an excavation. The complexity of this region regarding the high biodiversity, high sediment input, geomorphic settings, and oceanographic conditions linked to an understanding of reef development still remains a gap in our knowledge and needs to be fully evaluated. Hence, reef mapping and transects was employed to obtain reef geomorphology and associated habitat, detailed stratigraphy, combined with palaeoecological and geochronological analysis, enabling an investigation into how these reefs were able to persist under extreme environmental conditions as well as respond to Holocene sea level change.

Contemporary reef communities and habitat were investigated on the reef flat using visual assessments and descriptions as a first stage to obtain information on modern reef communities and digital towed cameras were then deployed to aid recognition and interpretation. Reef transects were established to log the abandoned reef exposures in the Cockatoo mine-pit and four transects were selected evenly spaced along the workable exposure. At each site, a vertical 0.7 m wide transect from the base to the top was logged, sampled and photographed to obtain information including: (i) the ratio of coral clasts and matrix; (ii) sediment characteristics (visual assessment of sediment composition and the Udden-Wentworth nomenclature); (iii) preliminary coral communities identification. Reef framework analysis and facies descriptions followed the terminology suggested by (Montaggioni, 2005), which highlights the growth of the dominant coral reef builders and environmental indicators. Position fixing was by DGPS tied to mine-site datum. Accelerator mass spectrometry (AMS) radiocarbon dating was used to establish a geochronologic record of reef accretion and recalibrated using CALIB Version 5.0.2 and calibration curve Marine04 (http://calib.qub.ac.uk/marine; accessed November 2012). All dated samples discussed in the text are calibrated in years Before Present (later written as cal y BP) with 68.2% (2σ) probability range. Transect data from each site were replotted relative to the Australian Height Datum (AHD), which is -3.987 m of the Cockatoo mine grid.

The towed camera investigations confirmed that the reef geomorphology and associated habitat of the Cockatoo fringing reefs is divided into three zones, comprising: 1) reef flat which is colonised mostly by branching *Millepora* and *Porites Cylindrica,* 2) outer reef flat dominated by *Turbinaria* and branching *Porites*, and 3) forereef slope with branching Acropora dominant. The contemporary live corals are not very common in the measured Holocene sections, suggesting that the Holocene reef communities lack reef flat habitat. The Holocene reflects mostly subtidal growth whereas the present reef is largely intertidal or very shallow subtidal. The reef stratigraphy in the Cockatoo mine-pit shows whole Holocene reef exposure, overlain by mine-rock overburden and underlain by hematitic breccia and Pleistocene calcretised reef. The foundation is Proterozoic hematitic sandstone.

The reef facies throughout the section is dominated by branching coral framestone unit with muddy matrix, but we can also find a domal dominant coral horizon in some sections, which doesn't continue laterally. The Holocene reef thickness measured is about 8 to 13 m, and that is the minimum thickness because the upper contact of the reef section is obscured by mine-rock overburden. The longest section of the reef stratigraphy shows that the early reef initiation was at ~9ky BP at the depth of 18 m AHD and the reef cessation was at ~3ky BP at the depth of 5.5 m AHD. This indicates that the reefs here have grown about 13 m within 6k years as sea-level rose. The matrix throughout the section is dominated by unconsolidated grey-green mud with up to 49% carbonate content, indicating that the sediment is sourced from land/terrestrial processes.

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The Holocene vertical reef and growth history of the Cockatoo fringing reefs shows that at the early stage of reef development, the reefs showed rapid growth with up to 11.4 mm/year at ~8ky BP and is classified as "keep-up" phase. The reef was interpreted establishing itself in a quite shallow environment, much light and high energy, so that the reefs grew keeping-up the sea-level. Following that, the sea-level overtook and the reefs lagged behind due to water depth, less light and low energy, thus the reefs experienced slowing growth with maximum growth rate only 2 mm/y which is classified as "catch-up" phase. At the end, when the reef nearly reached sea level, with increasing energy, much light, and shallow water, the reefs changed back to a "keep-up" phase with maximum 27 mm/year accretion rates.

As a comparison, Cockatoo growth history records keep-up initially with the Abrolhos curve in SW Australia with microtidal conditions and no-subsidence, but then lags behind, whilst Abrolhos reefs grew vertically to near sea-level until the highstand was recorded (Collins *et al.*, 1996). Scott reef of the oceanic shoals which represent macrotidal conditions and high subsidence rates since LIG, allows comparison of subsidence rates averaging 0.1 mm/y for Cockatoo and up to 0.45 mm/y for Scott reef (Collins *et al.*, 2011). Finally, with respect to the reef in GBR which has a muddy reef environment as does Cockatoo (Perry *et al.*, 2012), the reef foundation in GBR is shallower with much shorter history, very small (thinner) growth, and microtidal conditions.

This investigation is the first information on Holocene reef growth for the inshore Kimberley Bioregion and this also recorded the coastal subsidence of LIG substrate reef at Cockatoo Island with 0.1 mm/y rate. Comparison with turbid reefs of the inner GBR shows broad similarities in terms of mud-dominated matrix, sediment-tolerant coral, high coral cover, and similar growth rates with the exception of palaeoecological and contemporary reef communities which are similar in GBR but different at Cockatoo. The Cockatoo reef community has also evidenced adaptation to high sediment loads and frequent exposure. The study provides the first Holocene reef growth history for an inshore Kimberley reef within a biodiversity "hotspot".